

DEVELOPMENT OF SMART ACTUATORS FOR ACTIVE FLOW CONTROL AT LOW REYNOLDS NUMBER



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- » Development and applications of Particle Image Velocimetry for Flow Diagnostics
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- » Flow Diagnostics
- » Jet Flows
- » Flow control

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ABSTRACT

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Introduction:

The flight regime of small aerial vehicles fall under low Reynolds number flows where the phenomenon like laminar separation bubble and hysteresis significantly affect the performance of the airfoil. Active flow control^[1] is one of the important research areas that have high relevance to small aerial vehicle like UAVs and MAVs in the context of achieving high aerodynamic efficiency. It is a multidisciplinary research area combining sensing, actuation, flow physics and control. Here flow field is manipulated using a time dependent forcing system, typically to leverage a natural instability of the flow. Advantages include the ability to attain a large effect using a small and localized energy input. The rapid progress in the sensor, actuator and embedded hardware technologies has been significantly contributing to the development of different flow control techniques based on Piezo Actuator (PZT), plasma actuator, magnetostrictive, Electro Active Polymer (EAP) etc. Attempts have been made at NAL in the recent times in the development of smart actuators for the flow control using devices using PZTs, EAPs etc. In order to characterize these devices, the flow field and its modifications are being studied using advanced flow diagnostics tools like Laser Doppler Velocimetry (LDV) and Particle image Velocimetry (PIV). This paper presents work on the development smart devices for flow control and their effective deployment. The presentation will also address other issues of deployment of these devices in relatively small unmanned air vehicles.

Experimental Methods

Synthetic Jet Actuator:

Of the various types of active flow control methods oscillatory blowing using Synthetic Jet^[2] offers lot of promises in the low Reynolds number flow regimes. The benefit of employing synthetic jet as a flow control device is that they require no air supply and hence there is no need for piping, connections and compressors associated with conventional jets. The Synthetic Jet actuator comprised of a cavity, a small orifice connecting the cavity to the ambient fluid, and a flexible metal diaphragm that constitutes one side of the cavity. The schematic of the present configuration using piezo stack is shown in (Fig-1). The actuator disk consisted of a thin, brass shim on which piezo ceramic stack (*Cedrat APA 200M*.) is bonded. In this case the actuator is fixed to a rigid aluminum disk, which in turn is bonded to the copper shim. Neoprene gaskets and *O-rings* are used on either side of the copper shim to prevent air leak and also to allow optimum tightening of the shim. A photograph of the SJA assembly that uses piezo stack is shown in (Fig-2). A single component hotwire anemometer is used to characterize the jet by obtaining stream wise velocity profiles. A comparison of drive waveform showed that sine wave produced the maximum jet exit velocity compared to square and saw tooth waveforms. The plot of mean velocities profiles of synthetic jet at few stream wise locations is shown in (Fig.3). A Synthetic jet actuator was housed in NACA 4415 airfoil of 150 mm chord. The 2D jet was actuated at 314 Hz and the location of the slot is at x/c of 0.34. Boundary layer profiles were measured at different locations on the airfoil surface at $Re_c=100000$. The plot of the boundary layer profiles on the suction side for the angle of incidence 14 deg, is shown in Fig-4. The effect of Synthetic jet on the boundary layer flow separation control is evident from the plot. Detailed PIV measurements are planned to understand the mechanism of the leading edge flow separation control.

Electro Active Polymer:

Use of *static dimples* or *depressions* in the surface exposed to the flow in the control of laminar boundary layer separation is well known, like in golf balls, where the dimples induce a transition of the boundary layer by generation of streamwise vortices. A recent development in the dimple-based smart flow control is the application of Electro-Active Polymers (EAPs)^[3,4]. EAPs represent an emerging class of actuator materials that exhibit a tunable dimensional response to electrical stimulation. They exhibit superior performance than devices like shape memory alloys in terms of mechanical resilience, response speed, cyclic hysteresis and light weight. When a voltage is applied to the compliant electrodes on either side of the EAP material, the electrostatic pressure compresses EAP; as it is incompressible, it spreads in horizontal and lateral direction, increasing in area. When the electrodes of the actuators are continuously energized, a dimpled surface can be formed with a plurality of static depressions. The depth of the depression and its diameter will depend on the actual application. By providing a driving signal which varies over time, the dimple formation can also be varied in a periodical function of time. With a feed-back control, the actuators can be activated according to predicted frequency of vortex shedding in the separation region

Work carried out on the development of dimple-based flow control at NAL^[5] comprised of (i) selection of most the suitable EAP material, fabrication of optimized electrode pattern and the dimple actuators (ii) optimization of dimple parameters like diameter, depth, positioning, spacing between dimples in spanwise arrays and establishing the effectiveness by simulating static dimples on a 2D cylinder and airfoil. Initial tests on the characterization of dimple actuators involved the fabrication of a preliminary actuator with silver paste (Fig.5) and measurement of displacements on actuation with application of high voltages. Dimple actuators made of EAP *Nusil MED4905* film with concentric ring, silver/chrome-gold electrodes are being fabricated (Fig.6). Preliminary studies are being carried out on a 2D cylinder measurements towards the optimization of dimples (Fig.7,8). Qualitative (oil flow, smoke flow)/quantitative studies (pressure measurements/2-component LDV) show that the location of dimple arrays is the most crucial parameter. Detailed measurements for the characterization of dimples are in progress.

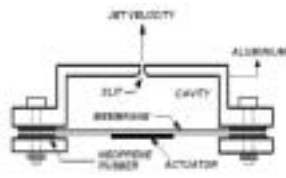


Fig-1: Schematic of piezostack Profiles



Fig-2: Photograph of the SJA Assembly

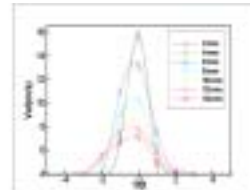


Fig-3: Transverse Velocity profiles

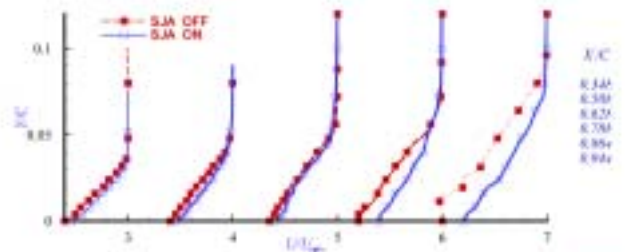


Fig-4: Boundary Layer Profiles on a NACA4415 airfoil with and without SJA Activation; $Re_c=100000$

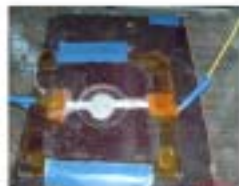


Fig-5: Preliminary actuator with silver paste



Fig-6: EAP actuator with concentric ring electrode



Fig-7: 2D circular cylinder without dimples



Fig-8: cylinder with dimples

Concluding Remarks:

A brief summary of the work being carried out using smart actuators for flow control at low Reynolds number is presented. Two types of actuators developed in-house viz., synthetic jet actuators and EAPs are described. Synthetic Jet Actuators constructed using PZT stack were implemented for flow separation control on a NACA 4415 airfoil at low Reynolds number. Studies showed the effectiveness of SJA in suppressing the boundary layer separation. Efforts are underway to implement the *Dimple on Demand* concept for flow control on a 2D cylinder. These techniques for flow control are of increasing relevance in the context of aerodynamic performance enhancement of unmanned air vehicles like MAVs and UAVs.

References

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